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Technical Report

EMERGENCY FUEL SUBSTITUTES FOR SPARK-IGNITION ENGINES

Tests Show That AVGAS and Mixtures of AVGAS and Diesel or Turbine Fuel Can Effectively Power Spark-Ignition Engines

June 1968

NAVAL FACILITIES ENGINEERING COMMAND

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

EMERGENCY FUEL SUBSTITUTES FOR SPARK-IGNITION ENGINES

Tests Show That AVGAS and Mixtures of AVGAS and Diesel or Turbine Fuel Can Effectively Power Spark-Ignition Engines

Technical Report R-589

Y-F015-20-02-005

by

Patrick J. Daly and William W. Watson

ABSTRACT

Under emergency or combat conditions, motor gasoline for spark-ignition engines may be temporarily unavailable, or at best in short supply. To determine the feasibility of substituting other fuels (AVGAS-115/145 aviation gasoline, DF-2 diesel fuel, and JP-5 turbine fuel), or mixtures thereof, for motor gasoline, the Naval Civil Engineering Laboratory operated three Hercules water-cooled engines and one Wisconsin air-cooled engine (all of them coupled to generators) on AVGAS-115/145 or mixtures of AVGAS-115/145 with DF-2 or JP-5. The tests proved conclusively that engines of this type can be effectively operated on such fuels for moderate periods of time. Specifically, 100% AVGAS-115/145, a mixture of 20% DF-2 plus 80% AVGAS-115/145, and a mixture of 30% JP-5 plus 70% AVGAS-115/145 were found to be satisfactory substitutes for motor gasoline for the periods of test operation (300 to 500 hours).

EVALUATION SHEET

Technical Report R-589

Title Emergency Fuel Substitutes for Spark-Ignition Engines. Tests Show That AVGAS and Mixtures of AVGAS and Diesel or Turbine Fuel Can Effectively Power Spark-Ignition Engines

Author Patrick J. Daly and William W. Watson

Task No. Y-F015-20-02-005

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INTRODUCTION

One of the problems anticipated in Navy Advanced Base Operations under emergency or combat conditions is the shortage of motor gasoline for spark-ignition engines. Under these conditions, supplies of aviation and diesel fuels, stocked in large quantities for aircraft and heavy equipment operation, may be available.

To examine the possibility of substituting other fuels, or mixtures thereof, for motor gasoline, the Naval Facilities Engineering Command (NAVFAC) instituted Work Unit Y-F015-11-04-633: Use of Mixed Aviation and Diesel Fuels in Spark-Ignition Automotive and Industrial Engines.

This report describes the results of that work, which was divided into four phases:

1. A literature search covering the use of fuel mixtures in spark igniting engines.
2. Chemical tests and analyses of fuels most likely to meet the established requirements.
3. Endurance testing of spark-ignition engines operating on several of the more promising fuels.
4. Engine dynamometer tests to determine the relative power outputs of the selected fuels.

Because only three fuels were likely to be available during emergency or combat conditions, this investigation was limited to: aviation gasoline, 115/145 (AVGAS-115/145); diesel fuel, grade 2 (DF-2); and aviation turbine fuel, type 5 (JP-5).

TESTING PROCEDURES

A literature search and preliminary refiners survey* suggested that fuel mixtures (by volume) which could be expected to perform in a manner similar to motor gasoline (MOGAS) are:

20% JP-4—80% AVGAS-115/145

10% JP-5—90% AVGAS-115/145

10% DF-2—90% AVGAS-115/145

15% Kerosene—85% AVGAS-115/145

Industry sources also indicated that 100% AVGAS-115/145 should be an acceptable substitute for MOGAS.

Laboratory Fuel Tests

A complete series of laboratory fuel tests and analyses was run on each of these fuel mixtures (Appendix A). Comparison of these data with MOGAS specifications indicated that certain adjustments would be advisable. These adjustments resulted in the following mixtures which had properties reasonably close to those of MOGAS (Table 1).

20% DF-2—80% AVGAS-115/145

30% JP-5—70% AVGAS-115/145

It was therefore decided to proceed to subject these two mixtures and 100% AVGAS-115/145 to engine testing.

No further consideration was given to mixtures containing JP-4 or kerosene, as these were not stocked in sufficient quantity in the Naval supply system.

Engine Endurance Test

The third phase of the evaluation program consisted of running a number of spark-ignition engines under load for 300 hours to determine the performance characteristics and damage possibilities of the test fuels.

Three newly reconditioned Hollingsworth 10-kw generator sets driven by identical, four-cylinder Hercules, water-cooled engines (Figure 1), and one new Winpower 7.5-kw battery-charging generator, driven by a four-cylinder Wisconsin air-cooled engine (Figure 2), were obtained from the Naval Construction Battalion Center, Port Hueneme, for use in testing the fuel mixtures. (See Appendix B for engine specifications.)

* Naval Civil Engineering Laboratory. Letter Serial No. 261 of 7 February 1967. Subject: Use of Mixed Aviation and Diesel Fuels in Spark-Ignition Automotive and Industrial Engines; Preliminary report on the

Table 1. Analyses of Fuel and Fuel Mixtures

Fuel	Distillation Temperature (°F) for Fraction–			Residue (%)	Reid Vapor Pressure (lb)	Octane Rating (motor)	Existent Gum (mg/100 ml)	Sulfur (%)	Corrosivene at 122°F (ASTM No
	10%	50%	90%						
Specification MIL-G-3056B combat gasoline type I (above 0°F)	140-158	194-239	275-356	2 (max)	8 (max)	83 (min)	4 (max)	0.25 (max)	1 (max)
Federal Specification VV-G-76a automotive gasoline (Class A)	158 (max)	257 (max)	365 (max)	2 (max)	9 (max)	82 (min)	4 (max)	0.15 (max)	1 (max)
Local MOGAS	132	247	356	1.5	8.4	85.2	14.8	0.13	1A
AVGAS-115/145	150	213	254	1.0	5.3	118.1	4.4	0.04	1A
20% DF-2–80% AVGAS-115/145[2]	159	229	529	1.0	5.6	99.3	36.8	0.12	1A
30% JP-5–70% AVGAS-115/145[2]	158	238	432	1.0	4.9	93.0	2.6	0.09	1A

[1] API Gravity $= \frac{141.5}{\text{Specific Gravity}} - 131.5$

[2] By volume.

A.

Table 1. Analyses of Fuel and Fuel Mixtures

%	Residue (%)	Reid Vapor Pressure (lb)	Octane Rating (motor)	Existent Gum (mg/100 ml)	Sulfur (%)	Corrosiveness at 122°F (ASTM No.)	Tetra-ethyl Lead (ml/gal)	Oxidation Stability (minutes)	API Gravity[1]	Btu/lb
356	2 (max)	8 (max)	83 (min)	4 (max)	0.25 (max)	1 (max)	3.0 (max)	480 (min)	–	–
ıax)	2 (max)	9 (max)	82 (min)	4 (max)	0.15 (max)	1 (max)	4.23 (max)	240 (min)	–	–
6	1.5	8.4	85.2	14.8	0.13	1A	2.43	240+	56.0	19,701
4	1.0	5.3	118.1	4.4	0.04	1A	4.57	240+	69.5	20,298
9	1.0	5.6	99.3	36.8	0.12	1A	3.43	240+	57.7	20,371
2	1.0	4.9	93.0	2.6	0.09	1A	2.67	240+	57.8	19,913

B.

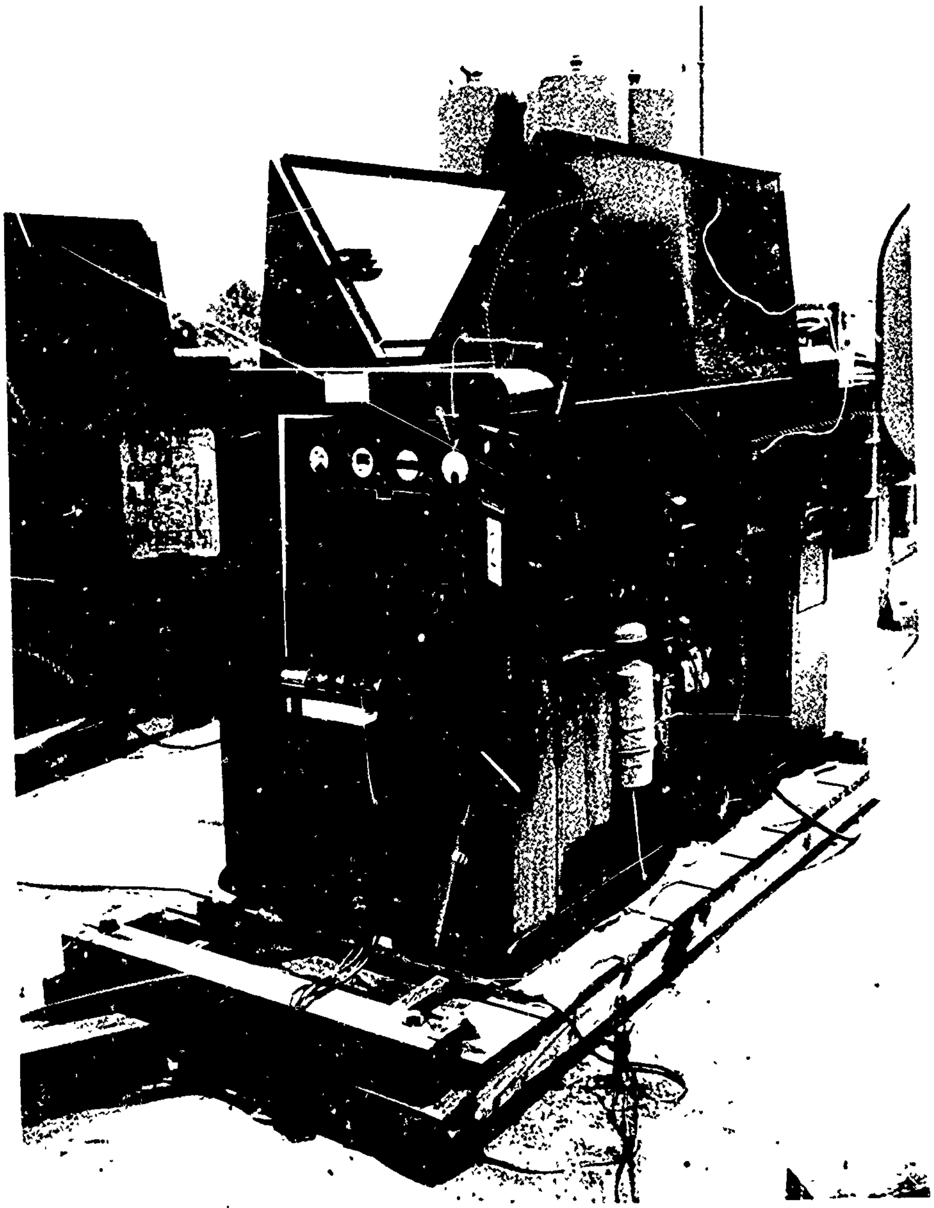

Figure 1. Unit 2 powered by a water-cooled Hercules engine.

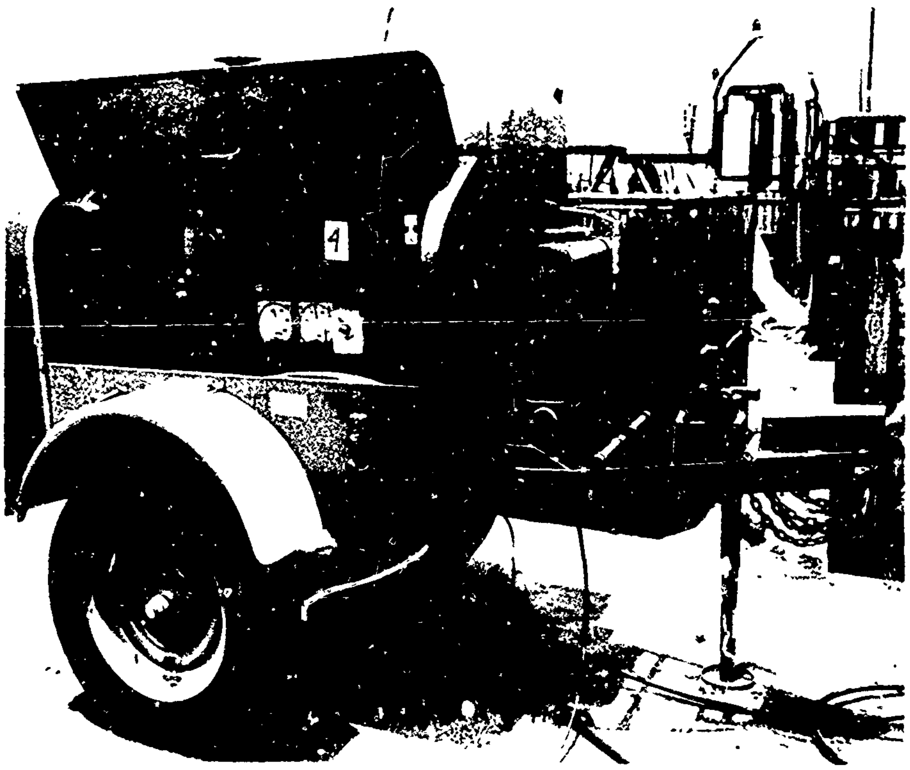

Figure 2. Unit 4 powered by an air-cooled Wisconsin engine.

Procedure. All generator sets were first given a preliminary 8-hour run-in on motor (regular) gasoline. The engines were then inspected, and cylinder compression readings were taken to determine pretest conditions. The results of the compression readings are given in Appendix C.

The generators were next connected to resistive load banks (Figure 3) loaded to approximately 90% of their rated capacity. They were run for 8 hours per day, 5 days a week, for a total of 300 hours. During this time the engines operated on fuels as follows:

Fuel Mixture	Engine	Test Unit No.	Navy Registration No.
20% DF-2–80% AVGAS-115/145	Hercules (water-cooled)	1	USN 51-07596
30% JP-5–70% AVGAS-115/145	Hercules (water-cooled)	2	USN 51-07598
100% AVGAS-115/145	Hercules (water-cooled)	3	USN 51-07595
100% AVGAS-115/145	Wisconsin (air-cooled)	4	USN 51-13529

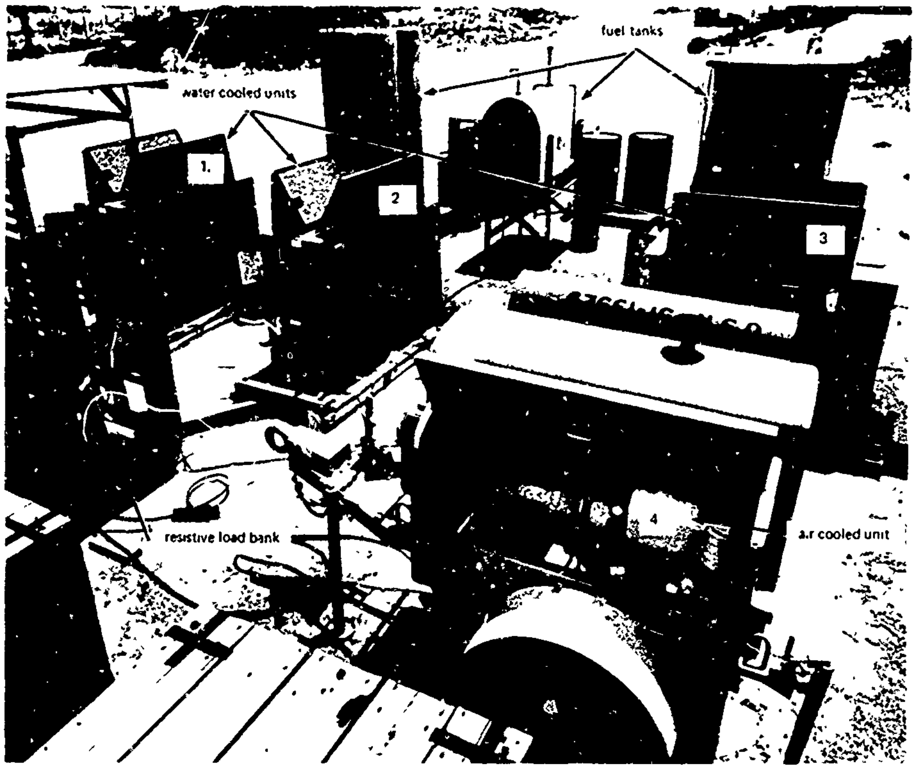

Figure 3. Mixed fuel endurance test site.

At the end of the successful 300-hour test, units 1 and 4 were scheduled to run an extra 200 hours on 100% AVGAS-115/145, in order to get additional background information on this fuel. Engine 4 completed only 137 hours of this second test before suffering a mechanical failure (broken piston ring and associated cylinder damage), which was not related to the fuel. Unit 1 completed the extra 200 hours of operation with no difficulty.

During the testing, the engines were serviced and maintained in accordance with manufacturer's recommendations. Cylinder compression tests were made at regular intervals during the test, and upon completion, the engines were disassembled for a detailed inspection of the operating parts. (See Appendix C for a summary of operating and inspection data.)

Results. The engine endurance tests indicated that:

1. Spark-ignition engines can be run on either of the mixed fuels, or on 100% AVGAS-115/145 without noticeable power loss or change in starting and operating characteristics.

2. Post-test inspection of the engines revealed no trace of damage or malfunction which could be directly related to the fuel used. It was noted that fairly heavy deposits did build up on the valves, spark plugs, and combustion chambers of all of the engines (Figures 4 through 7). In addition, in the engines run on 100% AVGAS-115/145, the crankcase oil showed some evidence of contamination by lead oxide after extended periods of operation.

3. Early in the testing, it was found that the constituents of the mixed fuels (that is, DF-2 and AVGAS in one case, and JP-5 and AVGAS in the other case) had to be forcibly mixed by a recirculating pump in order to obtain a good homogenous blend. Without mixing, the heavier constituent (DF-2 or JP-5) tended to settle to the bottom of the fuel storage tank. When fuel separation occurred, it was discovered that the engines could be run at reduced power on what was essentially pure JP-5 or DF-2, if starting aids (ether) were used and the ambient temperature was sufficiently high. This type of operation is not recommended, however, because of the likelihood of spark plug fouling, carbon buildup, and attendant loss of power.

4. The fuel consumption of engines running on mixed fuels was approximately the same for either mixture and averaged 10% less than that of the engines running on straight AVGAS-115/145 (Table 2).

Engine Dynamometer Test

To determine the loss of power, if any, caused by using these fuel mixtures in place of motor gasoline, the fuels were tested in an engine-dynamometer combination.

The test was performed at the Construction Battalion Center, Port Hueneme, using a General Motors 6V-478 spark-ignition engine driving a Clayton Model 8-200CE dynamometer. This engine was started on MOGAS and, after a thorough warmup, developed a maximum of 190 horsepower at 2,600 rpm with the throttle wide open. A series of test runs were then made successively on (1) 20% DF-2 plus 80% AVGAS-115/145, (2) 30% JP-5 plus 70% AVGAS-115/145, and finally on (3) 100% AVGAS-115/145. In each of these runs the engine was operated under wide-open throttle conditions, and loaded to 2,600 rpm. (See Appendix D.) The manufacturer's recommended ignition timing was set prior to the test, and was not changed throughout the entire procedure.

At no time during these full-power tests on either MOGAS, the two fuel mixtures, or AVGAS was there any appreciable change in power output.

Figure 4. Cylinder head condition for unit 1 after 300 hours' operation on DF-2–AVGAS-115/145 plus 200 hours on AVGAS-115/145.

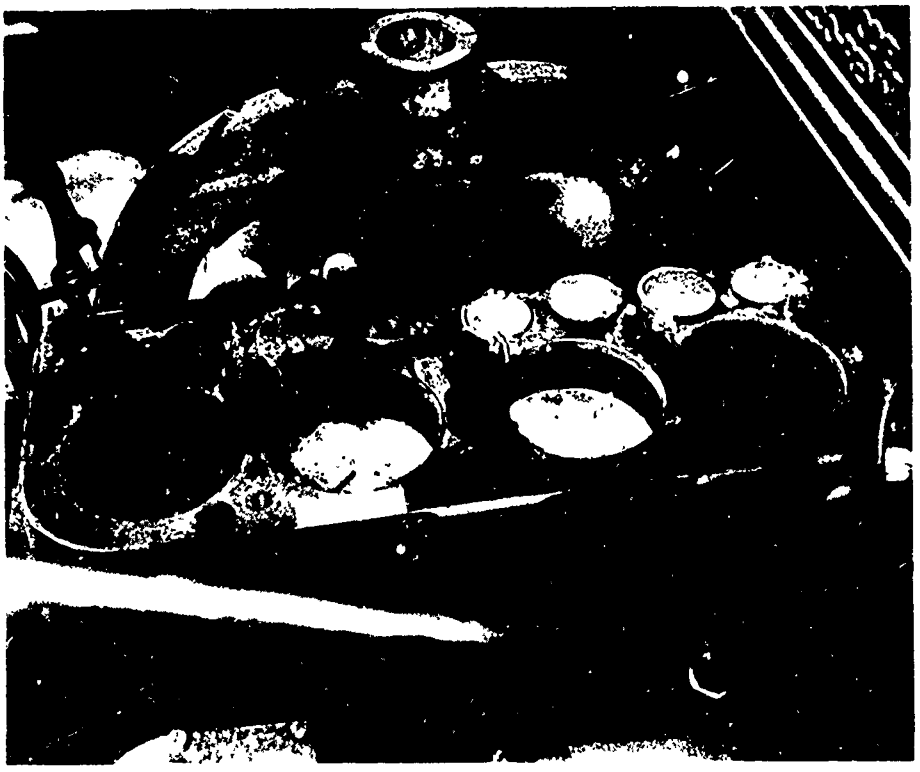

Figure 5. Cylinder and valve condition for unit 1 after 300 hours' operation on DF-2–AVGAS-115/145 plus 200 hours on AVGAS-115/145.

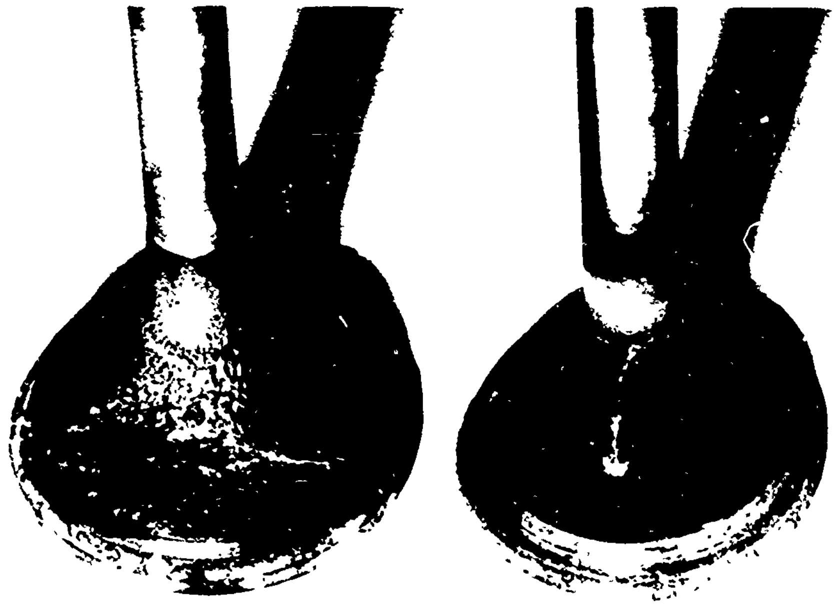

Figure 6. Valve condition for unit 1, cylinder 3, after 300 hours' operation on DF-2–AVGAS-115/145 plus 200 hours on AVGAS-115/145.

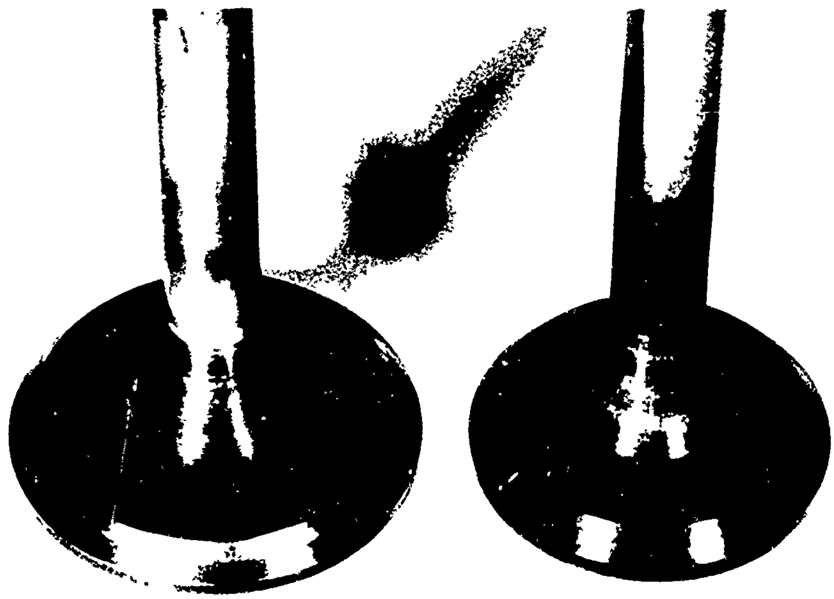

Figure 7. Valve condition (deposits removed) for unit 1, cylinder 3, after 300 hours' operation on DF-2–AVGAS-115/145 plus 200 hours on AVGAS-115/145.

Table 2. Fuel Consumption for Engine 3 on Different Fuels

Fuel Mixture	Fuel Consumption		
	gal/hr	gal/kw[1]	lb/kw
20% DF-2–80% AVGAS-115/145	1.77	0.197	1.20
30% JP-5–70% AVGAS-115/145	1.78	0.198	1.22
100% AVGAS-115/145	1.96	0.218	1.28

[1] Unit 3 had an output of 9.0 kw.

CONCLUSIONS

In general, either AVGAS-115/145 or one of the two mixtures (that is, 20% DF-2–80% AVGAS-115/145 or 30% JP-5–70% AVGAS- 15/145) will serve as an adequate substitute for motor gasoline in spark-ignition engines, provided the manufacturer's maintenance recommendations are closely followed. Scheduled maintenance is significant—particularly as regards oil changes and the cleaning of spark plugs. Contrary to popular opinion, there was ***no*** evidence of "burning" of the valves from the use of straight AVGAS-115/145.

Mixed fuels may be preferred to straight aviation gasoline, when AVGAS-115/145 is in limited supply. The mixed fuels yield better fuel consumption, in addition to extending the availability of AVGAS-115/145. The percentage of AVGAS-115/145 in the mixture may be increased to provide an easier starting cold-weather fuel, or decreased to obtain a less volatile hot-weather fuel. When fuels are mixed, extreme care must be taken to forcibly blend the constituents in order to avoid stratification in the fuel tank.

Appendix A

CHEMICAL AND PHYSICAL CHARACTERISTICS OF SELECTED FUELS AND MI

Fuel	Distillation Temperature (°F) for Fraction—			Residue (%)	Reid Vapor Pressure (lb)	Octane Rating (motor)	Existent Gum (mg/100 ml)	Sulfur (%)
	10%	50%	90%					
Specification MIL-G-3056B combat gasoline type I (above 0°F)	140-158	194-239	275-356	2 (max)	8 (max)	83 (min)	4 (max)	0.25 (max)
Federal Specification VV-G-76a automotive gasoline (Class A)	158 (max)	257 (max)	365 (max)	2 (max)	9 (max)	82 (min)	4 (max)	0 15 (max)
Local MOGAS	132	247	356	1.5	8.4	85.2	14.8	0.13
AVGAS-115/145	150	213	254	1.0	5.3	118.1	4.4	0.04
JP-4 turbine fuel	211	276	342	1.0	2.8	99.7	4.4	0.04
JP-5 turbine fuel	390	417	463	1.0	–	(40 est.)	0.4	0.20
DF-2 diesel fuel	452	513	595	1.5	–	(52 est)	6.2	0.34
20% JP-4–80% AVGAS-115/145[2]	160	222	287	1.0	5.7	99.7	0.6	0.03
20% JP-5–80% AVGAS-115/145[2]	156	224	411	1.0	5 5	93.2	1.8	0.07
30% JP-5–70% AVGAS-115/145[2]	158	238	432	1.0	4.9	93.0	2.6	0 09
10% DF-2–90% AVGAS-115/145[2]	153	218	362	1 0	5 5	99.8	22.4	0.08
20% DF-2–80% AVGAS-115/145[2]	159	229	529	1.0	5.6	99.3	36.8	0.12

[1] API Gravity $= \frac{141\ 5}{\text{Specific Gravity}} - 131.5$

[2] By volume.

A.

Appendix A

YSICAL CHARACTERISTICS OF SELECTED FUELS AND MIXTURES THEREOF

	Residue (%)	Reid Vapor Pressure (lb)	Octane Rating (motor)	Existent Gum (mg/100 ml)	Sulfur (%)	Corrosiveness at 122°F (ASTM No.)	Tetra-ethyl Lead (ml/gal)	Oxidation Stability (minutes)	API Gravity[1]	Btu/lb
6	2 (max)	8 (max)	83 (min)	4 (max)	0.25 (max)	1 (max)	3.0 (max)	480 (min)	–	–
x)	2 (max)	9 (max)	82 (min)	4 (max)	0.15 (max)	1 (max)	4.23 (max)	240 (min)	–	–
	1.5	8.4	85.2	14.8	0.13	1A	2.43	240+	56.0	19,701
	1.0	5.3	118.1	4.4	0.04	1A	4.57	240+	69.5	20,298
	1.0	2.8	99.7	4.4	0.04	1A	0.0	240+	53.1	19,966
	1.0	–	(40 est.)	0.4	0.20	1A	0.0	–	40.2	19,697
	1.5	–	(52 est.)	6.2	0.34	1A	0.0	–	31 9	19,411
	1.0	5.7	99.7	0.6	0.03	1A	3.54	240+	65.8	20,297
	1.0	5.5	93.2	1.8	0.07	1A	3.86	240+	63.5	20,168
	1.0	4.9	93.0	2.6	0.09	1A	2.67	240+	57.8	19,913
	1 0	5.5	99.8	22.4	0.08	1A	4.32	240+	64.7	20,123
	1.0	5.6	99.3	36.8	0.12	1A	3.43	240+	57 7	20,371

B.

Appendix B

ENGINE AND GENERATOR SPECIFICATIONS

Units 1, 2, and 3

USN Nos. 51-07596, 51-07598, and 51-07595

Hollingsworth 10-kw electric generating set

Model. NA-105-AC

Serial Nos.: 123, 125, and 122

Engine: Hercules model IXB3ER

Type: Four-cylinder L-head

Displacement: 133 in.^{3} (3-1/4-inch bore x 4-inch stroke)

Rating: 32.35 horsepower at 1,800 rpm

Cooling: liquid

Generator: Hollingsworth alternator model E 1054 M777

Output: 120/208-volt, 60-cycle, 3-phase current

Rating: 10 kw, 16 kva, 0.625 pf

Unit 4

USN No. 51-13529

Winpower 7-1/2-kw battery-charging generator

Model: D-7518-5

Serial No.: F-811-3

Engine: Wisconsin Model MVF4D-4

Type: Four-cylinder, V-block, L-head

Displacement: 107.7 in.^{3} (3-1/4-inch bore x 3-1/4-inch stroke)

Rating: 19.5 horsepower at 1,800 rpm

Cooling: air

Generator: Winpower

Output: 48-volt DC, 155-ampere current at 1,800 rpm

Rating: 7.5 kw

Appendix C

GENERATOR SET ENDURANCE TEST DATA

Table C-1. Summary of Generator Set Operating Data

(Ambient temperature—65°F to 85°F)

Unit No.		Fuel	Percent of Full Load	Average Load (kw)	Voltage	Amperage	Fuel Consumption		
							gal	gal/hr	gal/kw
Phase I Testing (300 hours)									
1		20% DF-2—80% AVGAS-115/145	90	9.0	120	75	480	1.6	0.19
2		30% JP-5—70% AVGAS-115/145	90	9.0	120	75	485	1.6	0.19
3		100% AVGAS-115/145	90	9.0	120	75	579	1.9	0.22
4[1]	First 95 hr	100% AVGAS-115/145	68	5.1	113	45	141	1.5	0.28
	Last 205 hr	100% AVGAS-115/145	85	6.4	122	52	341	1.7	0.26
Phase II Testing (200 hours)[2]									
1		100% AVGAS-115/145	83	8.3	120	69	355	1.8	0.21
4		100% AVGAS-115/145	85	6.4	122	52	227	1.7	0.26

[1] Unit 4 inadvertently run at a reduced load setting of 68% for first 95 hours. Remaining 205 hours run at 85% load setting.

[2] Unit 4 failed from a broken piston ring after 137 hours of additional (Phase II) testing, Uni[illegible] operated satisfactorily for the additional 200

A.

Table C-1. Summary of Generator Set Operating Data

(Ambient temperature–65°F to 85°F)

Fuel	Percent of Full Load	Average Load (kw)	Voltage	Amperage	Fuel Consumption			Oil Consumption (qt)
					gal	gal/hr	gal/kw	
Phase I Testing (300 hours)								
2–80% 115/145	90	9.0	120	75	480	1.6	0.19	6-1/2
–70% 115/145	90	9.0	120	75	485	1.6	0.19	11
/GAS-115/145	90	9.0	120	75	579	1.9	0.22	6-1/2
/GAS-115/145	68	5.1	113	45	141	1.5	0.28	1-1/2
/GAS-115/145	85	6.4	122	52	341	1.7	0.26	6
Phase II Testing (200 hours)[2]								
/GAS-115/145	83	8.3	120	69	355	1.8	0.21	4
/GAS-115/145	85	6.4	122	52	227	1.7	0.26	9-1/2

t a reduced load setting of 68% for first 95 hours. Remaining 205 hours run at 85% load setting.

en piston ring after 137 hours of additional (Phase II) testing, Unit 1 operated satisfactorily for the additional 200 hours of testing.

B.

Table C-2. Record of Cylinder Compression Tests

(All values in psig)

Hours of Testing	Generator Set Unit No 1				2				3				4			
	Cylinder No.				Cylinder No.				Cylinder No.				Cylinder No.			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
0	92	98	98	95	100	87	87	100	108	100	100	105	80	68	84	68
40	113	100	110	97	110	95	87	98	112	104	98	95	77	65	85	75
190	100	104	100	100	98	88	90	85	108	103	76	88	76	70	84	54
300	100	89	102	93	100	85	95	102	105	68	90	103	75	62	80	35
350	113	102	94	97	–	–	–	–	–	–	–	–	70	55	88	48
400	98	104	105	101	–	–	–	–	–	–	–	–	67	50	86	34
450	100	98	98	102	–	–	–	–	–	–	–	–	81	72	90	23
500	104	98	97	107	–	–	–	–	–	–	–	–	–	–	–	–

Appendix D

DYNAMOMETER TEST PROCEDURE

Dynamometer: Clayton 200-horsepower water adsorption type, Model 8-200 CE

Engine: GMC V-6 Model 478 (reconditioned)

Engine Compression Ratio: 7.5

Engine Spark Setting: 2-1/2 degrees before TDC with 31 degrees camdwell

Procedure: The engine was started on MOGAS and set to obtain 190 horsepower at 2,600 rpm with the throttle wide open. After each 5 minutes of steady operation, the fuel intake was switched to a different fuel. The engine ran continuously while the fuel changes were made. The fuels were tested in the following order: MOGAS, AVGAS-115/145, JP-5—AVGAS-115/145, DF-2—AVGAS-115/145, and MOGAS.

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13 ABSTRACT

Under emergency or combat conditions, motor gasoline for spark-ignition engines may be temporarily unavailable, or at best in short supply. To determine the feasibility of substituting other fuels (AVGAS 115/145 aviation gasoline, DF-2 diesel fuel, and JP-5 turbine fuel), or mixtures thereof, for motor gasoline, the Naval Civil Engineering Laboratory operated three Hercules water-cooled engines and one Wisconsin air-cooled engine (all of them coupled to generators) on AVGAS 115/145 or mixtures of AVGAS 115/145 with DF-2 or JP-5. The tests proved conclusively that engines of this type can be effectively operated on such fuels for moderate periods of time. Specifically, 100% AVGAS 115/145, a mixture of 20% DF-2 plus 80% AVGAS 115/145, and a mixture of 30% JP-5 plus 70% AVGAS 115/145 were found to be satisfactory substitutes for motor gasoline for the periods of test operation (300 to 500 hours).

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Spark-ignition engines						
Emergency fuels						
100% AVGAS 115/145						
Diesel fuel-AVGAS mixture						
Turbine fuel-AVGAS mixture						

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